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The HETE Triggering Algorithm

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Abstract. The High Energy Transient Explorer uses a triggering algorithm for gamma-ray bursts that can achieve near the statistical limit by fitting to several background regions to remove trends. Dozens of trigger criteria run simultaneously covering time scales from 80 msec to 10.5 sec or longer. Each criteria is controlled by about 25 constants which gives the flexibility to search wide parameter spaces. On orbit, we have been able to operate at 6σ, a factor of two more sensitive than previous experiments.

Gamma-ray bursts (GRBs) occur at unpredictable times and satellite telemetry bandpasses are too limited to send every photon to the ground in real time. Thus, GRB experiments usually have on-board triggering systems to detect when a GRB is occurring and to switch operation modes to capture the event with maximum time and energy resolution. Most previous experiments (Vela, PVO, ISEE-3, Ginga, BATSE) employed a system that looked for "significant" increases in the photon count rate over a background count rate. Such increases are usually searched for over a few (e.g., 3) time scales that have ranged from 0.064 sec to 4 sec. For the background count rate, these systems took an average of the count rate from a period assumed to be well before the bursts (e.g., from 16 sec to 30 sec before the trigger sample).

The definition of a "significant" trigger has usually been how many standard deviations ("σ") the candidate time sample exceeds the expected count rate *assuming Poisson statistics*. Because of the use of Poisson statistics in the definition of the trigger, it is a common misconception that trigger algorithms are guarding against statistical fluctuations. The σ level is usually never set below ~ 11 and, yet, there are still many false triggers. Obviously, the cause of false triggers is not statistical fluctuations. In most experiments (e.g., PVO, Ginga, ISEE-3), the σ level was 11 and 90% of the triggers were, in fact, not GRBs. BATSE also had a threshold equivalent to $\sim 11\sigma$; it used 5.5 σ in the second brightest illuminated detector which translates to $\sim 11\sigma$ in the brightest illuminated detector. BATSE achieved $\sim$ 50% false trigger rate because many triggers could be rejected on-board by crude locating which was able to nullify many false triggers when the source appeared to be inside the satellite (i.e., particle events) or coming from the sun.

Rather than guarding against statistical fluctuation, on-board triggers need to be designed to avoid false triggers, often caused by trends in the data. Consider the scenario in the figure. If one only has a single background region before the burst (labeled "Back$_1$"), a slight trend can make the count rate in a candidate trigger period to appear to be statistically significant. This situation becomes worst for larger experiments. For example, the 5000 cm^2 Burst Alert Telescope on the Swift satellite will have a background rate of $\sim$ 17 kHz. A 4% trend in the background is enough to have the appearance of a 5.5 σ statistical fluctuation. Variations in the particle flux in low earth orbit can easily make a factor of two variation in tens of seconds. Eleven σ was selected in the past because such a threshold would eliminate triggers from most trends over the time scales used in the triggering, a reason that does not involve statistical fluctuations.

In contrast to BATSE which required a uniform and easily understood trigger to have bursts with well defined properties, our goal is to capture as many and as varied GRBs as possible. Thus, on the High Energy Transient Explorer (HETE) we have implemented an extremely flexible triggering algorithm designed to remove trends and achieve triggering close to the Poissonian limit. A large number of triggers run simultaneously, each defined by $\sim$ 25 constants. HETE was launched with 31 such triggers, controlled by $>$ 700 constants. As we learn more about the actual background, we can upload new triggers or new constants for existing triggers.

HETE consists of three instruments. The FREGATE gamma-ray scintillators were built by CESR of France and covers the energy range 6 to 400 keV. The Wide Field X-ray Monitor (WXM) is a proportional counter-based coded aperture built by the RIKEN Institute of Japan and Los Alamos. It covers 2 to 25 keV and can provide locations with a point spread function of 34 arc minutes. The Soft X-ray Cameras (SXC) are CCD-based coded apertures built by MIT that cover 0.5 to 10 keV and can provide locations with a point spread function of 30 arc seconds. SCX and FREGATE have their own triggering systems. In

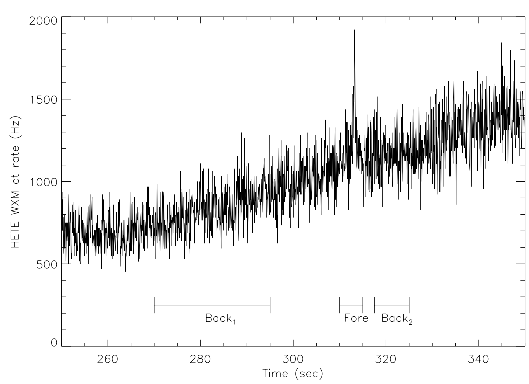

Fig. 1. A triggering scenario where a trend causes a false trigger. Previous on-board triggering systems have only used a single background period (e.g., "Back$_1$") before the candidate trigger sample (i.e., "Fore"). The trend can give a false trigger. In HETE, we use two background regions which can either be both before the trigger sample or bracket the trigger sample. Many triggers run simultaneously, covering a wide temporal and energy parameter space.

this paper, we describe the WXM triggering software which is also applied to FREGATE. Each of the three instruments can trigger the other instruments.

The HETE trigger algorithm works in the past. It can use either one background region or two and they can either be both before the candidate trigger sample (and therefore extrapolate to remove a trend) or they can bracket the time sample (and therefore interpolate to remove a trend, the situation depicted in the figure). The background regions are used to predict the count rate during the candidate foreground sample and the net counts are characterized by the number of σ the deviation appears to be.

The triggering runs asynchronously with the data collection (which is based on 80 ms samples). When invoked (typically once per sec but perhaps longer), the triggering algorithm tests all the samples which have occurred in each trigger since the last time it was invoked (perhaps 20 to 40 new samples each second) and reports the best one. The trigger algorithm can sense increases in either the FREGATE scintillators, or the WXM proportional counters, or a combination of both. We can control which of the four FREGATE detectors or four WXM detectors are used in each trigger.

The following is a summary of the major parameters that define each trigger. A set of flags indicate whether the trigger applies to WXM, FREGATE, both WXM and FREGATE, or neither. For both FREGATE and WXM we specify the range of detectors to be used and the range of energies to be used. We usually use all detectors for both systems. For energy ranges, we currently use 2 to 20 keV for all of the WXM triggers and 20 to 300 for all of the FREGATE triggers. One parameter tells if there will be one background region or two.

We can specify the start times and durations of each of the backgrounds relative to the current time. Typically, the background before the candidate sample is about 16 sec and the background afterwards is 1 or 2 sec. We also specify how frequently the backgrounds must be recalculated. (For triggers looking for short bursts it is unnecessary to recalculate the background for each new candidate sample.) Other parameters define the start, duration, and the spacing between the foreground samples. Typically, we use foreground candidate durations of 80 msec to 10.5 sec. The spacing between evaluations is adjustable which allows us to have samples of length ΔT and sample them more frequently than ΔT to check more phases. The threshold for declaring a trigger is set in units of σ^2. The trigger algorithm provides to the WXM imaging algorithm the start and stop times of the first background region and the candidate trigger region. These are used to determine, on-board, the location of the GRB.

The bracketing background works best. The single background cannot tolerate a slope and the two backgrounds before the candidate time can produce false triggers whenever there is a change in slope. One disadvantage of the bracketing system is the determination of the on-board location (and subsequent report to the ground) is delayed until after the second background period.

This triggering algorithm is capable of using all available on-board computing power and, as such, we often will only operate a subset of the available triggers.